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DURALUMIN

by

E. Unger and E. Schmidt.

Translated from
Technische Berichte Vol. III - Section 6.

by

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The use of duralumin in the construction of aircraft makes an account of the properties of this material desirable especially with reference to its working qualities as developed by experience.

Composition, Specific Gravity and Melting Point.

Duralumin is made in various compositions and has, with the exception of small quantities of impurities, the following composition:

Aluminum	95.5	to	93.2	percent
Magnesium			.5	"
Copper	3.5	"	5.5	"
Manganese	.5	"	.8	"

Lead, tin and zinc which, as is well known, have an unfavorable influence upon the permanence of aluminum alloys, are not found in duralumin.

The specific gravity of duralumin varies according to composition and hardness from 2.75 to 2.84. The melting point is about 650° C.

Duralumin is made under this name by the Durener Metallwerke, Duren (Rhld), and under the name of Bergmetall by Carl Berg, Eveking (Westf.).

Working of Duralumin

Like other metals, duralumin can be rolled into plates and shapes and behaves in a similar manner, in that the elongation decreases as the hardness of rolling increases. Tube blanks, however, can be made only by pressing and not by the oblique rolling method.

Fig. 1 shows the increase in tensile strength and decrease in elongation of a duralumin plate as its thickness is reduced by cold rolling from 7 mm. to 2 mm. The strength increases from 41 kg. to about 54 kg. per sq.mm. while the elongation falls from 22.7 to 2.3 percent. The curve shows that the elongation decreases very rapidly with the very first reduction in thickness.

However, duralumin can be worked hot at a temperature of about 400° C. very well.

Tempering

Duralumin can be tempered, like steel, by heating and sudden cooling. For this purpose plates, tubes, and shapes are heated to between 480° and 510° and quenched, then aged; that is, the treated material is simply set aside. The original strength characteristics are very nearly restored after the quenching but the tensile strength continues to grow with the time of ageing, from 35 to 50 kgs. per sq.mm. The elongation does not decrease but remains at least the same and usually increases slightly. In practice the greatest strength is reached after about 5 days of ageing.

When heated to over 530° C. duralumin becomes unusable. Consequently the treating is carried on in a bath of nitrates whose temperature can be carefully regulated and watched. During the ageing of the metal work cannot be done on it which would change the section as in that case the strength will not increase any more. After the completion of ageing, the material can be re-rolled in order to obtain smooth surfaces. The strength is thereby increased at the expense of elongation.

Fig. 2 shows the increase of strength during ageing. The tensile strengths were determined by the Ericson test with 0.385 as a coefficient. This value was obtained from the experiments described below.

Experiments have been made (see Fig. 3) by the Durener-Metallwerke to determine the most favorable quenching temperature. The curve "a" shows the variation in the strength of duralumin which had been aged for 4 days with the variation of quenching temperature. Curve "b" shows the strength immediately after the quenching. The strengths were determined in both cases by the Ericson test.

As the material may warp in tempering it is not good practice to temper riveted parts. Such parts should be tempered before they are riveted.

Strength Properties

Duralumin is delivered in various compositions which have different properties according to the purpose for which it is intended to be used. It is therefore important that the concern supplying the material should be informed regarding the nature of the working proposed. In Table 1 below are assembled the strength figures of some duralumin compositions made by the Durener-Metallwerke.

Symbol for Composition	Condition	Method of Preparing	Elastic limit kg/mm^2	Tensile strength kg/mm^2	Elongation in %	Modulus of elasticity kg/cm^2	Sections available
681b 1/3	tempered only	tempered	24 to 26	38 to 40	20	about 500,000	Tubes, plates, strips, bars & shapes.
681b 1/3	1/2 hard	tempered and cold rolled.	30	40 to 42	16 to 14	500,000	Tubes plates, strips, bars.
681a	tempered only	tempered	25 to 27	38 to 40	20 to 18	600,000	Tubes, plates, strips, bars & shapes.
	hard	tempered & cold rolled	30 to 32	44 to 46	11 to 10	-	Tubes, plates, strips, bars & shapes.
681h	tempered only	tempered	26 to 28	38 to 42	18 to 15	600,000	Tubes, plates, strips, bars & shapes.
	HARD	tempered and cold rolled	32 to 34	45 to 48	11 to 10		Tubes plates, strips, bars.
N	tempered only	forged rivets are tempered	20	32 to 34	18 to 14	Shear strength up to 6 mm. diam. 25 kg/mm^2	Finished rivets.

The modulus of elasticity of the hard composition 681a was found by the Technischen Hochschule Aachen to be 700,000 kgs. per sq.cm. Making allowance for the possible effect of vibration on the modulus of elasticity it appears better to use not more than 650,000 kgs. per sq. cm. in computations.

In judging as to the suitability of a material for use in stressed parts not only the tensile strength but also the ductility is of great importance. This can be determined by bending strips backward and forward through 180° over a definite radius - usually 5 to 10 mm.- the number of bends before fracture being taken as a measure. Other conclusions as to the ductility can be obtained from the Ericson test (see Fig. 4). The plate to be tested is pressed through a ring, b, by a head, a, until a tear shows on the upper surface of the sheet. The depth of the impression is then a measure of the ductility.

In Table 2 there are compared strength values, numbers of bends (over 5 mm. radius and through 180°) and depths of impression as observed on Bergmetall plates and steel plates of equal thicknesses.

Table 2.

Strengths, No. of bends, depths of impressions for Steel and Bergmetall.

Thickness of Plate	Steel				Bergmetall			
	Strength kg/mm²	Elongation %	No. Bends	Depths of impression mm	Strength kg/mm²	Elongation %	No. Bends	Depth of impression mm.
0.5	36	10.5	76	7.2	47	10.5	33	5.5
1	34	15.3	26	95	47	11.0	3	4.2
2	39	12.0	10	10.9	45	11.0	Fractured at 90°	3.4
3	40	17.7	6	13	48	14.1	Fractured at 60°	3.0
4					48	9.7	Fractured at 45°	2.8

Although the strength values of the steel plates are less than those of the duralumin plates, nevertheless one can compare the figures as to number of bends and depths of impression without correction, since it is possible to obtain steel plate with higher strength which also possesses great ductility.

The number of bends (see Fig, 5) for both metals decreases with increased thickness. For steel, however, they lie considerably higher than for duralumin. The difference is least for plates under .5 mm. in thickness. For thicker plates of duralumin the number of bends decreases very rapidly. A plate 2 mm. thick breaks over a 90° bend; a plate 4 mm. thick over a 45° bend. From these results duralumin might be referred to as "cold short" for thicknesses greater than 1 mm. This property makes it unsuitable for highly stressed parts which must at the same time withstand vibrations. This is of prime importance in connection with the bent lug plates which are ordinarily used in aircraft for taking wire terminals. In these lugs vibrations undoubtedly occur during flight which would reduce the strength of the duralumin and might cause sudden fracture.

Exactly how vibrations influence the modulus of elasticity has not yet been determined, although experiments along this line are already under way.

A comparison of the depth of impression of steel and duralumin shows (see Fig. 6) that for steel the depth of impression increases with the thickness of the material while for duralumin it decreases. As a result of a peculiarity of the testing machine used the greatest stress occurred at a point which was from 5 mm. to 6 mm. from the vertex of the depression. In this locality the material began to flow before cracking. It is obvious that thick plates of ductile material may be stretched more easily on the upper surfaces and consequently deeper impressions obtained than with thin plates, since for thick plates more material can flow before fracture occurs. A similar course of reasoning can be used to explain the decrease of depth of impression with increasing thickness of plate in the case of material of less ductility. On the upper surface of the test pieces there occur high tensile stresses at the point above mentioned, which increase with the strength of the plate. As the material flows only to a small degree, cracks very soon appear and extend into the interior. The process described can be followed on the sections of a steel plate of about 40 kgs. per sq.mm. strength and a duralumin plate, Fig. 8. The flow before fracture of the steel plate is plainly recognizable while the duralumin plate shows hardly a sign of it.

Fig. 9 is a photograph of a test sample of strong duralumin plate after fracture in which the material suddenly split in all directions.

For flanging and pressing tempered duralumin is consequently suitable only in the thin gauges.

Influence of heat and cold.

Heat has an important influence on the strength of duralumin. According to the results obtained in tests by the Central Bureau for Scientific Investigation, Neubabelsberg, when heated the strength decreases 10% for an increase in temperature of 100° and about 20% for an increase of 150° (see Fig. 10). The loss in strength increases with the increase of temperature. The elongation increases on first heating to a hardly appreciable extent, while between 150° and 200° it decreases. At 250° the elongation becomes the same as at room temperature. With further heating the elongation increases with increasing temperature. Consequently wherever duralumin is exposed to heat the possible decrease of strength must always be considered.

As opposed to the foregoing the influence of cooling on the strength properties is less unfavorable. The Central Bureau for Scientific Investigation has made tests on this also (see Table 3).

Table 3.

Influence of Cold on the Strength of Duralumin.

Testing Temperature	The bar was tested in	Tensile Tests: Limit of stretch & strain	Tensile Tests: Ult. Strength kg/mm²	Tensile Tests: Elongation %	Impact Test: Work of breaking kg/mm²
+ 20°	Air	24.0	42.5	21.9	2.6
0	Snow	23.6	43.0	21.8	2.6
- 20	Mixture of snow and table salt	24.0	43.7	23.1	2.7
- 40	Mixture of snow & calcium chloride.	24.0	44.0	22.1	2.7
- 80	CO_2 snow	25.2	44.4	22.7	2.7
- 190	Liquid Air	32.3	53.7	28.7	2.6
+ 20	Air	23.0	42.3	23.3	2.6

The strength and elongation increase somewhat with the decrease in temperature. The work represented by the blow in the impact tests is not decreased when material is affected by cold so that one can safely assume that the cold encountered in flight has no unfavorable influence on duralumin.

Experiments on the influence of weathering on the strength of duralumin, which have been carried on by the Durener-Metallwerke for 3 years, have shown that no observable decrease in the strength properties can be noticed (see Table 4).

Table 4.

Effect of Weathering on the Strength of Duralumin.

Testing Data Alloy 681a	Dec. 1909 Strgth kg/mm^2	Dec. 1909 Elongation %	Nov. 1910 Strength kg/mm^2	Nov. 1910 Elongation %	Nov. 1911 Strength kg/mm^2	Nov. 1911 Elongation %	Dec. 1912 Strength kg/mm^2	Dec. 1912 Elongation %
Round Bar	41.7	20	42.2	21	42	21.1	42.9	18.3
Bar (thick)	39.1	20	38.7	19.6	39.3	18.9	40	20
Bar (thin)	42.0	20	39.1	18.0	39.3	18	42.3	16.5
Wire (thick)	48.0	20.1	45	20.1	44.3	19.7	44.5	19.8
Wire (thin)	46.3	20	44	19.6	42.5	18.7	43.2	18.5

The Durener-Metallwerke have also carried on for about a year, experiments on the influence of the electrolytic effect from junctions of duralumin with iron or steel. These were made by riveting duralumin bars to iron plates and then placing them in artificial sea water. There resulted only an insignificant destruction of the iron and a reduction in weight of the bars of about .23% so that no considerations exist against the use of duralumin and iron junctions in aircraft.

Summary

Duralumin has a strength of 35 to 40 kgs. per sq.mm. and an elongation of 10 to 15%. The stretching strain limit lies very high, about 28 to 32 kgs. per sq. meter. The modulus of elasticity is about 600,000 to 700,000 kgs. per sq.cm. It is very brittle especially in thicknesses above 1 mm. and consequently sensitive to bending to and fro (alternating).

Bent Plate Fittings, with bent lugs which must resist vibration are best not made out of duralumin but of sheet steel. For stressed parts which while in flight are exposed to an increase in temperature of more than 100° C the use of duralumin is objectionable unless a correspondingly smaller strength value is used in computations. Cold has no harmful influence on duralumin. The joint between iron and steel and duralumin can be made without electrolytic action occurring. Pieces, which for better working must be heated, must be in all cases re-tempered after completion.

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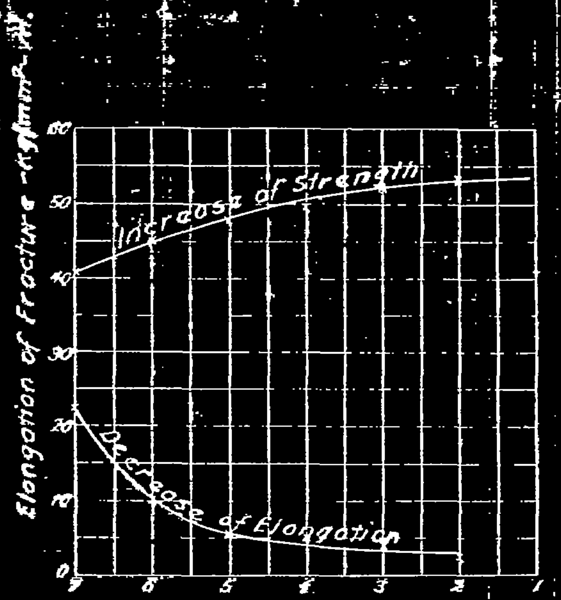

Fig 1

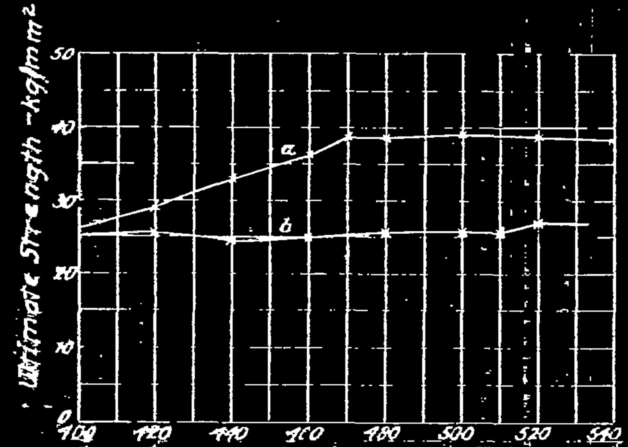

Fig 3

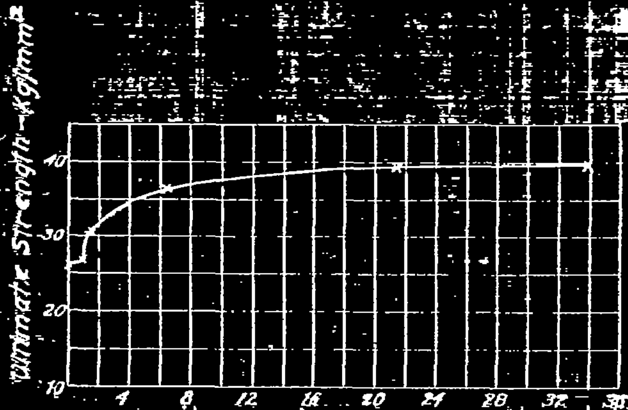

Fig 2

Figs. 1, 2 & 3.

Ericsons Test Apparatus

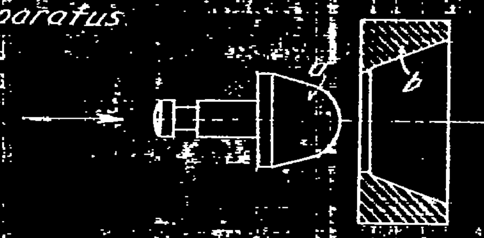

Fig 4.

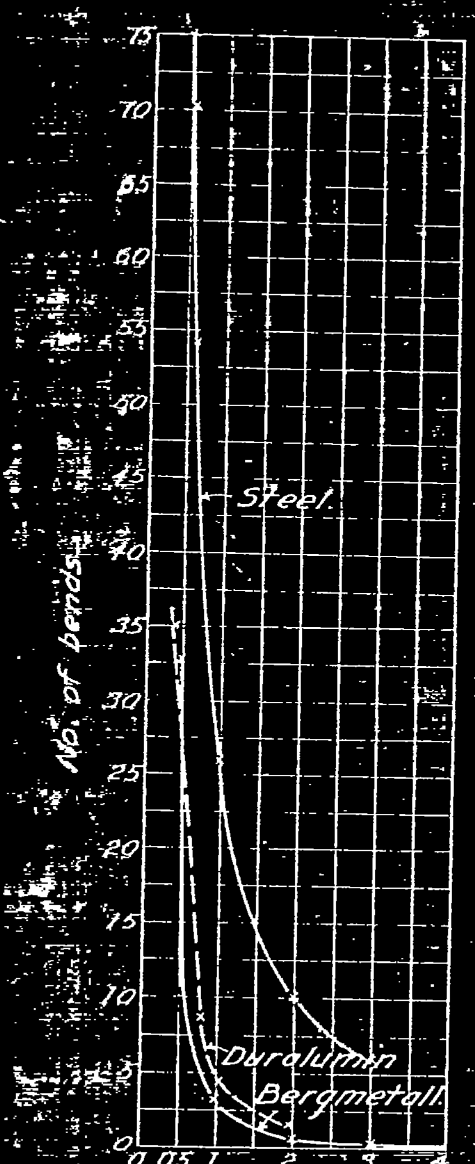

Fig. 5.

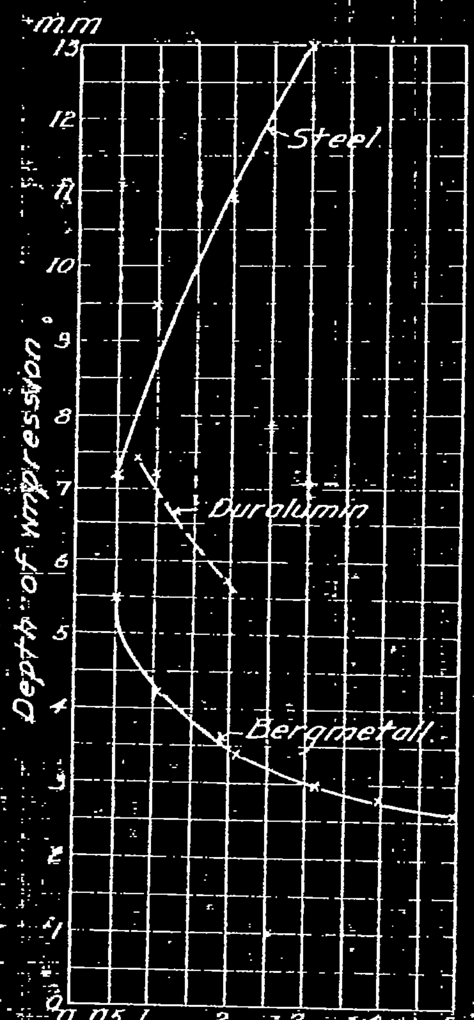

Fig. 6.

Figs. 4, 5, 6.

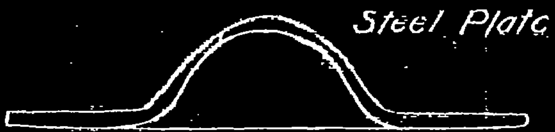

Fig. 7.

Fig. 8.

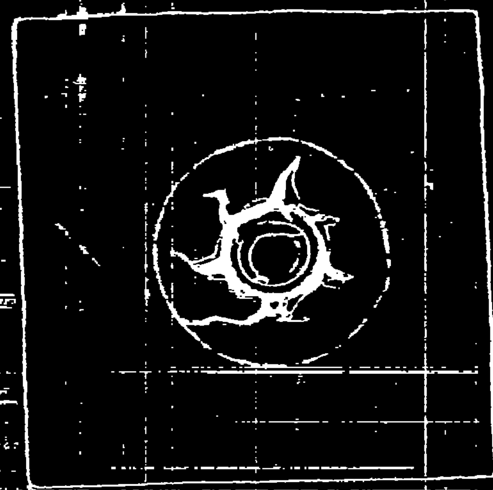

Fig. 9.
Outside Fracture of Duralumin Plate.

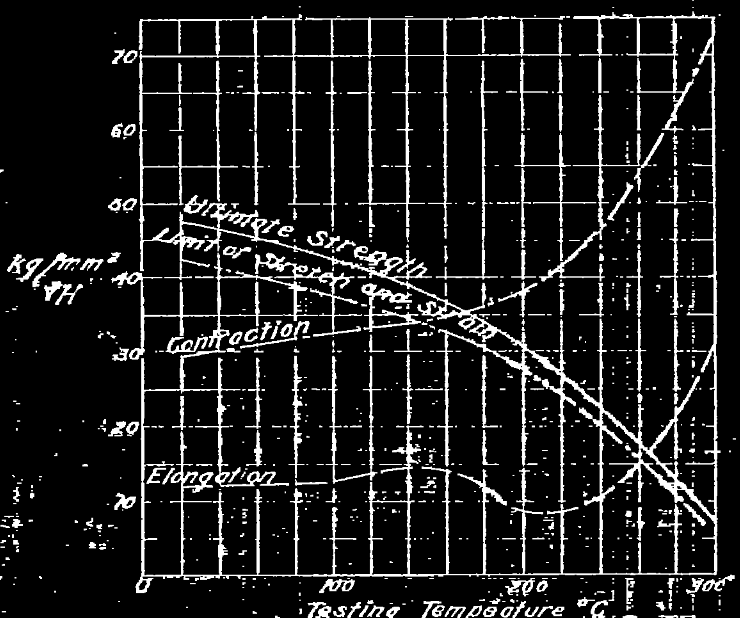

Fig. 10.